PCT

WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 :
H01P 7/10, 1/208

A1

(11) International Publication Number: WO 96/42118

(43) International Publication Date: 27 December 1996 (27.12.96)

(21) International Application Number: PCT/SE96/00768

(22) International Filing Date: 13 June 1996 (13.06.96)

(30) Priority Data:
9502137-4 13 June 1995 (13.06.95) SE

(71) Applicant *(for all designated States except US)*: TELEFONAKTIEBOLAGET LM ERICSSON [SE/SE]; S-126 25 Stockholm (SE).

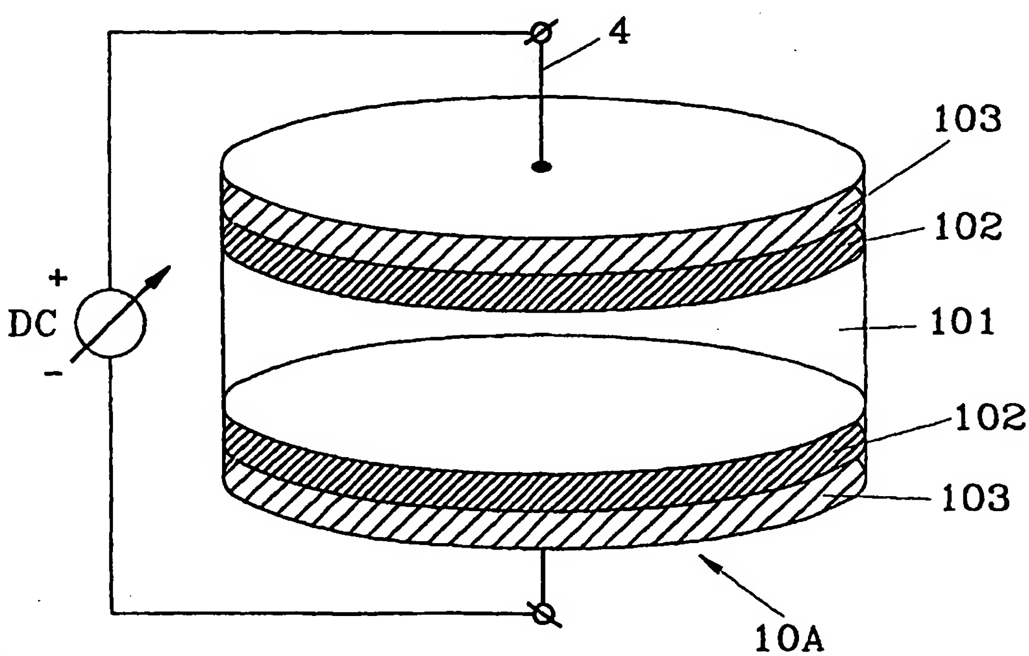
(72) Inventors; and
(75) Inventors/Applicants *(for US only)*: WIKBORG, Erland [SE/SE]; Lundblads Väg 3, S-182 33 Danderyd (SE). VENDIK, Orest [RU/RU]; Korabelostroitelay 42, S. Petersburg, 199155 (RU). KOLLBERG, Erik [SE/SE]; Diabasvägen 7, S-437 00 Lindome (SE). GEVORGIAN, Spartak [SE/SE]; Daniel Petterssons Gata 2B, S-413 20 Göteborg (SE).

(74) Agents: BERGENTALL, Annika et al.; Göteborgs Patentbyrå, P.O. Box 5005, S-402 21 Göteborg (SE).

(81) Designated States: AL, AM, AT, AU, AZ, BB, BG, BR, BY, CA, CH, CN, CZ, DE, DK, EE, ES, FI, GB, GE, HU, IL, IS, JP, KE, KG, KP, KR, KZ, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, TJ, TM, TR, TT, UA, UG, US, UZ, VN, ARIPO patent (KE, LS, MW, SD, SZ, UG), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG).

Published
With international search report.

(54) Title: TUNABLE MICROWAVE DEVICES



(57) Abstract

The invention relates to tunable microwave devices (10A) comprising a substrate (101) of a dielectric material which has a variable dielectric constant. At least one superconducting film (102) is arranged on at least parts of the dielectric substrate (101). The dielectric substrate (101) comprises a non-linear dielectric bulk material.

FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AM	Armenia	GB	United Kingdom	MW	Malawi
AT	Austria	GE	Georgia	MX	Mexico
AU	Australia	GN	Guinea	NE	Niger
BB	Barbados	GR	Greece	NL	Netherlands
BE	Belgium	HU	Hungary	NO	Norway
BF	Burkina Faso	IE	Ireland	NZ	New Zealand
BG	Bulgaria	IT	Italy	PL	Poland
BJ	Benin	JP	Japan	PT	Portugal
BR	Brazil	KE	Kenya	RO	Romania
BY	Belarus	KG	Kyrgystan	RU	Russian Federation
CA	Canada	KP	Democratic People's Republic of Korea	SD	Sudan
CF	Central African Republic			SE	Sweden
CG	Congo	KR	Republic of Korea	SG	Singapore
CH	Switzerland	KZ	Kazakhstan	SI	Slovenia
CI	Côte d'Ivoire	LI	Liechtenstein	SK	Slovakia
CM	Cameroon	LK	Sri Lanka	SN	Senegal
CN	China	LR	Liberia	SZ	Swaziland
CS	Czechoslovakia	LT	Lithuania	TD	Chad
CZ	Czech Republic	LU	Luxembourg	TG	Togo
DE	Germany	LV	Latvia	TJ	Tajikistan
DK	Denmark	MC	Monaco	TT	Trinidad and Tobago
EE	Estonia	MD	Republic of Moldova	UA	Ukraine
ES	Spain	MG	Madagascar	UG	Uganda
FI	Finland	ML	Mali	US	United States of America
FR	France	MN	Mongolia	UZ	Uzbekistan
GA	Gabon	MR	Mauritania	VN	Viet Nam

Title:
TUNABLE MICROWAVE DEVICES

FILED OF THE INVENTION

The present invention relates to microwave devices and components comprising dielectric substrates and conductors in the form of superconducting films. The tunability of such devices is obtained through varying the dielectric constant of the dielectric material. Examples on devices are for example tuneable resonators, tuneable filters, tuneable cavities etc. Microwave devices or components are important for example within microwave communication, radar systems and cellular communication systems. Of course there are also a number of other fields of application.

STATE OF THE ART

The use of microwave devices is known in the art. In "High Temperature Superconducting microwave circuits" by Z-Y Shen, Artech House 1994, dielectric resonators are discussed which are based on TEM01 delta modes. A dielectric resonator is clamped between thin High Temperature Superconducting films (HTS) which are deposited on separate substrates and thus not directly on the dielectric. These resonators fulfil the requirements as to cellular communication losses and power handlings at about 1-2 GHz. It is however inconvenient that the dimensions of the HTS films and the dielectric substrates at these frequencies (e.g. 1-2 GHz) are large and moreover the devices are expensive to fabricate. Furthermore they can only be mechanically tuned which in turn makes the devices (e.g. filters) bulky and introduce complex problems in connection with vibrations or microphonics. WO 94/13028 shows integrated devices of ferroelectric and HTS films. Thin epitaxial ferroelectric films are used. Such films have a comparatively small dielectric constant and the tuning range is also limited and the microwave losses are high. Furthermore there is a highly non-linear

current density in thin HTS film coplanar waveguides and microstrips. This results from the high current density at the edges of the strips, D.M. Sheen et al, IEEE Trans. on Appl. Superc. 1991, Vol. 1, No. 2, pp. 108-115. The applicability of these integrated HTS/ferroelectric thin film devices is therefore limited and they are not suitable as for example low-loss narrow-band tuneable filters.

Generally tuneable filters are important components within microwave communication and radar systems as discussed above. Filters for cellular communication systems for example, which may operate at about 1-2 GHz occupy a considerable part of the volume of the base stations, and often they even constitute the largest part of a base station. The filters are furthermore responsible for a high power consumption and considerable losses in a base station. Therefore tuneable low loss filters having high power handling capabilities are highly desirable. They are also very attractive for future broad band cellular systems. Today mechanically tuned filters are used. They have dielectrically loaded volume resonators having dielectric constants of about 30-40. Even if these devices could be improved if materials were found having still higher dielectric constants and lower losses, they would still be too large, too slow and involve too high losses. For future high speed cellular communication systems they would still leave a lot to be desired.

In US-A-5 179 074 waveguide cavities wherein either part of or all of the cavity is made of superconducting material are shown. Volume cavities with dielectric resonators have high Q-values (quality) and they also have high power handling capabilities. They are widely used in for example base stations of mobile communications systems. The cavities as disclosed in the above mentioned US patent have been reduced in size and moreover the losses have been reduced. However, they are mechanically tuned and the size and the losses are still too high. WO 94/13028 also shows a number of tuneable microwave devices incorporating high temperature

superconducting films. However, also in this case thin ferroelectric films are used as already discussed above, and the size is not as small as needed and the losses are too high. Furthermore, the tuning range is limited.

"1 GHz tunable resonator on bulk single crystal SrTiO plated with YBaCuO films." by O.G. Vendik et al, Electronics Letters, Vol. 31, No. 8, April 1995 shows a tunable resonator on bulk single crystal $SrTiO_3$ plated with YBCO films. This device however suffers the drawbacks of not being usable above T_c (the critical temperature for superconductivity). This means for example that no signals could pass if the temperature would be above T_c which may have serious consequences in some cases. These devices cannot be used unless in a superconducting state.

Furthermore the superconducting films are very sensitive and since they are in no way protected this could have serious consequences as well. In general, in the technical field, only dielectrica e.g. photoresist have been used to protect superconducting films.

SUMMARY OF THE INVENTION

Thus tuneable microwave devices are needed which can be kept small, are fast and which do not involve high losses. Dévices are also needed which can be tuned over a wide range and which do not require mechanical tuning. Devices are needed which have a high dielectric constant particularly at cryogenic temperatures and particularly devices are needed which fulfil the abovementioned needs in the frequency band of 1-2 GHz, but of course also in other frequency bands. Still further devices are needed which can operate in superconducting as well as in non-superconducting states. Devices are also needed wherein the superconducting films are less exposed. Particularly devices are needed which can be electrically tuned and reduced in size at a high level of microwave power.

Therefore a device is provided which comprises a substrate of a dielectric material with a variable dielectric constant. At least

one superconducting film is arranged on parts of the dielectric substrate which comprises a non-linear dielectric bulk material. The substrate comprises a single crystal bulk material and the superconducting film or films comprise high temperature superconducting films. A normal conducting layer is arranged on the or each side of the superconducting film(s) which is/are opposite to the dielectric substrate. The tuning is provided through producing a change in the dielectric constant of the dielectric material and this may particularly be carried out via external means and particularly the electrical dependence of the dielectric constant used for example for voltage control or but also the temperature dependence of the dielectric constant can be used for controlling purposes. Particularly an external DC bias voltage can be applied to the superconducting film. Alternatively a current can be fed to the films but it is also possible to use a heating arrangement connected to the superconducting film or films and in this way change the electric constant of the dielectric material. Bulk single crystal dielectrics particularly bulk ferroelectric crystals, have a high dielectric constant which can be above for example 2000 at temperatures below 100 K, in the case of high temperature superconducting films below T_c, which is the transition temperature below which the material is superconducting. Krupka et al in IEEE MTT, 1994, Vol. 42, No. 10, p. 1886 states that bulk single crystal ferroelectrics such as $SrTiO_3$ have small dielectric losses such as $2,6x10^{-4}$ at 77 K and 2 GHz and very high dielectric constants at cryogenic temperatures.

However, according to WO 94/13028 and "A High Temperature Superconducting Phase Shifter" by C.M. Jacobson et. al in Microwave Journal Vol. 5, No 4, Dec. 1992 pp 72-78 states that electrical variation to change the dielectric constant of bulk material is small and thus far from satisfactory. Moreover, microwave integrated circuit devices are exclusively made by thin film dielectrica which according to the known documents is necessary.

The dimensions of the devices according to the invention can be

very small, such as for example smaller than one centimetre at frequencies of about 1-2 GHz and still the total losses are low. This however merely relates to examples and the invention is of course not limited thereto.

Particularly the superconducting film arrangement and the dielectric substrate are arranged so that a resonator is formed and the superconducting film(s) may be arranged on at least two surfaces of the dielectric substrate. According to different embodiments the superconducting films may be arranged directly on the dielectric substrate or a thin buffer layer may be arranged between the superconducting films and the dielectric substrate. One aspect of the invention relates to the form of the parallel plate resonator wherein the dielectric substrate may comprise a resonator disc. More particularly at least one superconducting film (and normal conducting film arranged thereon) may have an area which is smaller e.g. particularly somewhat smaller, than the corresponding area of the dielectric substrate on which it is arranged in order to provide coupling between degenerate modes thus providing a dual mode operation resonator. Even more particularly, in one aspect of the invention, it wises at providing a two-pole tuneable passband filter (or a multi-pole tuneable filter). Means may be provided for controlling the coupling between the two or more degenerate modes.

According to still another aspect of the invention it is aimed at providing a tuneable cavity. One or more resonators are then enclosed in a cavity comprising superconducting material or non-superconducting material. In the case of non-superconducting material, it may particularly be covered on the inside with a thin superconducting film. The cavity still more particularly comprises a below cut-off frequency waveguide. The device comprises coupling means for coupling micro-wave signals in and out of the device. These can be of different kinds as will be further described in the detailed description of the invention.

Moreover, in a particular embodiment of the invention second tuning means may be provided for fine-tuning or calibrating of the resonance frequency of the dielectric substrate of the resonator. These means may comprise a mechanically adjustable arrangement and it can for example also comprise thermal adjusting means etc.

In a particular embodiment a cavity as referred to above may comprise two or more separate cavities each comprising at least one resonator. These resonators are connected to each other via interconnecting means and form a dual mode or a multi-mode resonator.

One example on a dielectric substrate is a material comprising $SrTiO_3$ and the superconducting films may be so called YBCO-films (YBaCu). The invention is applicable to a number of different devices such as tunable microwave resonators, filters, cavities etc. Particular embodiments relate to tunable passband filters, two- three- or four-pole tunable filters etc. Other devices are phase shifters, delay lines, oscillators, antennas, matching networks etc.

Tunable microwave integrated circuits are described in the copending patent application "Arrangement and method relating to tunable devices" filed at the same time by the same applicant and which is incorporated herein by reference.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will in the following be further described in a non-limiting way under reference to the accompanying drawings in which:

FIG 1a illustrates an electrically tuneable parallel plate resonator having a cylindrical form,

FIG 1b illustrates an electrically tuneable parallel plate resonator having a rectangular form,

FIG 2 shows an experimentally determined plot of the temperature dependence of the dielectric constant of the single crystal bulk material for two different voltages,

FIG 3 schematically illustrates the dependence of the dielectric constant of $SrTiO_3$ on applied DC tuning voltage for a number of different temperatures,

FIG 4 illustrates how the ratio of dielectric constants for two different voltages varies with temperature,

FIG 5 illustrates how the resonant frequency depends on applied DC tuning voltage for the circular resonator of Fig 1a, with YBCO and Cu electrodes,

FIG 6 illustrates the experimentally determined dependence of the loaded Q-factor of a circular resonator as illustrated in Fig 5 on the applied DC tuning voltages,

FIG 7a illustrates a circular dual mode parallel plate bulk resonator,

FIG 7b illustrates a rectangular dual mode parallel plate bulk resonator,

FIG 8a illustrates a cross-sectional view of a parallel plate resonator enclosed in a cavity forming a below cut-off frequency waveguide with probe couplers,

FIG 8b illustrates a cross-sectional view of a parallel plate resonator enclosed in a cavity forming a below cut-off frequency waveguide with loop couplers,

FIG 9 illustrates a cross-sectional view of a reduced-size cavity with a parallel plate resonator,

FIG 10a illustrates a cross-sectional view of a parallel plate resonator in a cavity with a frequency adjustment screw,

FIG 10b illustrates an embodiment similar to that of Fig 10a but with a differently located adjustment screw,

FIG 10c illustrates an embodiment similar to that of Figs 10a and 10b but wherein the frequency adjusting means comprises an electrical heater,

FIG 11a illustrates a cross sectional side view of a four-pole electrically tuneable adjustable filter in a superconducting cavity housing,

FIG 11b illustrates a top view of the filter of fig 11a and

FIG 12 illustrates a cross sectional view of a three-pole electrically tuneable filter with coupled circular parallel plate resonators.

DETAILED DESCRIPTION OF THE INVENTION

Fig 1a illustrates a first embodiment in which a nonlinear bulk dielectric substrate 101 with a high dielectric constant is covered by two superconducting films 102, 102. The low loss nonlinear dielectric substrate 101 and the two superconducting films 102, 102, (below their critical temperatures) comprise a microwave parallel plate resonator 10A with a high quality factor, Q-factor. Via a variable DC-voltage source a tuning voltage is applied. In an advantageous embodiment the superconducting films 102, 102 comprise high temperature superconducting films HTS. These HTS films are covered by non-superconducting high-conductivity films or normally conducting films 103, 103 such as for example gold, silver or similar. These protective films 103, 103 serve among others the purpose of providing a high Q-factor also above the critical temperature T_c and to serve as ohmic contacts for an

applied DC tuning voltage. Moreover, these films serve the purpose of providing a long term chemical protection and protection in other aspects as well of the HTS films 102, 102. A variable DC voltage source is provided for the application of a tuning voltage bias to the films. The voltage is supplied via a lead or conducting wires 4 and when a biasing voltage is applied, the dielectric constant of the nonlinear dielectric substrate 101 is changed. In this way a change in the resonant frequency (and the Q-factor) of the resonator is obtained. In Fig. 1a a circular resonator 10A is illustrated. In Fig. 1b a rectangular resonator 10B is illustrated. These are the two simplest forms of resonators and for them the analysis of the performance is quite simple and the resonant frequencies can be predicted in a precise way. The rectangular and the circular shapes have different modes and modal field distributions and the application of these shapes in the area of microwave devices such as filters etc. is substantially given by the modal field distribution.

The dielectric substrate 101 for example comprises bulk single crystal strontiumtitanateoxide $SrTiO_3$. The superconducting films 102 may comprise thin superconducting films and the protective layer 103 may comprise a normal metal film as referred to above. The reference numeral 4 illustrates the leads for the DC biasing voltage current; this reference numeral remains the same throughout the drawings even if it can be arranged in different manners which however are known per se and need not be explicitly shown herein.

In the embodiments of Figs. 1a and 1b an external DC bias voltage is supplied. It is however also possible to make use of a temperature dependence of the dielectric constant of the nonlinear dielectric bulk material instead of the voltage dependence. In illustrated embodiments the HTS films are deposited on the surfaces of a dielectric resonator disc of a cylindrical or a rectangular shape. However as referred to above, the shapes can be chosen in an arbitrary way and the thin films are deposited on at least two of the surfaces. Generally the low total loss of the device is due

to the low dielectric loss of bulk single dielectric crystals, for example ferroelectric crystals and the low losses in the superconducting films, particularly high temperature superconducting films. In further embodiments which will be described later on in the detailed description one or more resonators are enclosed in a cavity, particularly a superconducting cavity and the losses are low also in the cavity walls (below T_c). In bulk single crystal dielectrics the nonlinear changes due to for example DC biasing (tunability) are larger than for example those in thin ferroelectric films as known from the state of the art. Furthermore tunability is improved through the deposition of the superconducting films which have a high work function for the charge carriers directly onto the surface of the dielectric or ferroelectric resonator. This prevents charge injection into the ferroelectrics and thus also the "electrete effect" along with freeze-out of the AC polarization at the boundary. As referred to above, in parallel plate resonators the HTS films are covered by non-superconducting films e.g. of normal metal. Through the use of these films 103 the devices are usable also above T_c of the HTS-films. Otherwise the HTS-films (e.g. YBCO) would only act as poor conductors above T_c. Through the use of the films 103 however the devices still operate as resonators also above T_c. This means that the device operates both in a superconducting and in a non-superconducting state. Advantageously the thickness of the HTS-films each exceed the London penetration depth, which is the depth where current and magnetic fields can penetrate. In advantageous embodiment the HTS-film thickness may be about 0,3 µm. This is of course merely given as an example and the invention is not limited thereto. If the superconducting film thickness exceeds the London penetration depth λ_L, the field of the superconductor does not reach or penetrate the normal conductor which would lead to increased microwave losses. When the temperature exceeds T_c, λ_L does not exist. The normal conductor plates then act as resonator plates. If the temperature is below T_c, λ_L is smaller than the thickness of the superconducting films.

The thickness of the normal metal plate, e.g. Au, Ag advantageously exceeds the skin depth. Furthermore, through the normal conductor plates good ohmic contact is provided when a DC-bias is applied. This reduces prevents Joule heat generation which would have given degraded superconducting properties of the HTS-material. The normal conductors also serve as contacts for the voltage or current DC-bias and as protection layers. The normal metal may for example be Au or Ag or any other convenient metal. A further advantage of these protective films is that even in case of e.g. a failure in the cooling system used to maintain a sufficiently low temperature, the losses are kept at a low level and the device still operates.

In an advantageous embodiment, not illustrated in the figures, it is possible to arrange thin buffer layers between the superconducting films and the dielectric substrate, for example a ferroelectric substrate, in order to improve the quality of the superconducting films at the deposition stage and to stabilize the superconducting film-dielectric system by controlling the chemical reactions (e.g. exchange of oxygen) between the superconducting films and the dielectric substrate. Advantageously the thickness of the superconducting film is higher than the London penetration depth as referred to above. Furthermore the thickness of the protective layer 103 of normal metal constituting ohmic contacts is larger than the skin depth and gives reasonably high Q-factors even at temperatures above the critical temperatures T_c of the superconducting film as discussed above. Although the non-superconducting films 103 are not explicitly illustrated in e.g. the embodiments relating to Fig. 7a-12, they are advantageously provided also in these embodiments.

Fig 2 illustrates an experimentally determined temperature dependence of the dielectric constant of a single crystal bulk material, in this case $SrTiO_3$ the frequency is here 1 kHz and the thickness of the bulk material is 0,5 mm. Two curves are illustrated, for 0 V and 500 V respectively. For the same resonator (for example the one illustrated in Fig. 1a) and with the same

frequency and the same thickness as in Fig. 2, the variation in dielectric constant with the DC tuning voltage is illustrated for different temperatures. In Fig. 4 the temperature dependence of the ratio of the dielectric constants at 0 V and 500 V for $SrTiO_3$ is illustrated for a frequency of 1 kHz.

Figures 5 and 6 illustrate experimentally determined dependencies of the resonant frequency and the loaded Q-factor respectively for a circular resonator as shown in Fig. 1a on the applied DC tuning voltage. The upper curves indicate the losses where only superconducting films are used and the lower curves indicate the losses where only Cu films (without superconductors) are used.

Figs. 7a and 7b illustrate two different embodiments of dual mode parallel plate bulk resonators 20A, 20B. At least one of the superconducting films 702a, 702b of each respective embodiment have smaller dimensions than the substrate of dielectric material 701. In Fig. 7a the resonator 20A is circular whereas in Fig. 7b the resonator 20B is rectangular. Since the dimensions of the superconducting films, particularly high temperature superconducting films, are reduced, the radiative losses are reduced. Since the superconducting films are smaller than the dielectrica, dual mode operation of the bulk parallel plate dielectric resonator is enabled in that coupling between at least two degenerate modes is possible. The coupling between the two degenerate modes of the resonators 20A, 20B can be controlled via controlling means 705a, 705b. In Fig. 7a the controlling means comprises a protrusion 705a or a strip of superconducting film which gives a facility to control the coupling between the two or more degenerate modes. In Fig. 7b the coupling means is formed in that a piece 705b of the superconducting film is cut-off in one of the corners. In and out refer to coupling in and coupling out respectively of microwaves. If the coupling means 705a, 705b are provided, two-pole tuneable passband filters are obtained.

Advantageously non-superconducting layers are arranged on the

superconducting films as discussed above under reference to the embodiments of Figs 1a, 1b. The coupling means 705a, 705b may also be formed, either alone or in combination with superconducting material with the normal conductor plate denoted 103 in Figs. 1a and 1b (not shown in Figs. 7a, 7b). Moreover thin buffer layers between the superconducting films and the dielectric substrate can be provided or not.

In order to provide a multimode device a number of alternating layers of dielectrical and superconducting films respectively, advantageously with non-superconducting films on the superconductors, can be arranged on top of each other, having different sizes in agreement with the embodiments of Figs. 7a and 7b.

In the following a number of embodiments will be discussed wherein one or more resonators are enclosed in a cavity. Particularly they are enclosed in a below cut-off frequency cavity waveguide. Such a cavity can be made of bulk superconducting material or of a normal metal covered by superconducting films, particularly high temperature superconducting films, on the inside to reduce its microwave losses and to reduce its dimensions. Inductive or capacitive couplers are used to couple the microwave signals in and out of the parallel plate resonator via holes in the walls of the cavity. If a DC voltage is used for the tuning (as referred to above also, temperature tuning can be applied), the tuning voltage is applied by a thin wire 4 through an insulated hole 9 in the wall of the cavity. In Fig. 8a the tuning voltage is applied by the wire 4 through the insulated hole 9 in a wall of the cavity housing 806a. The resonator comprises a dielectric substrate 801 which on at least two sides is covered by superconducting films 802. Non-superconducting conducting plates may be arranged thereon as discussed above. Connectors 807a, 808a are provided for the input and output respectively of microwave signals. Probes 10 are provided for coupling the microwave signals in and out of the resonator. This embodiment thus shows an example on coupling.

In Fig. 8b the resonator 30A is denoted with the same reference numerals as in Fig. 8a and the cavity housing is denoted 806b. In this case the connectors 807b, 808b are located on the opposite side walls of the cavity 806b. Loops 11 are provided for coupling microwave signals in and out of the resonator 30b and this is an example on loop coupling. These embodiments show inductive couplings. Below cut-off frequency waveguides made of bulk superconducting material or of normal metal with a high temperature superconducting film provided on the inside of the normal metal are used for enclosing the parallel plate resonator in order to screen out external fields, achieve low losses, facilitate the application of voltage tuning (or any other convenient manner of tuning) and to reduce the size of the resonator.

Fig. 9 illustrates a device 40 wherein a resonator 41 is enclosed in a superconducting cavity 906 wherein a DC tuning voltage is supplied via the lead 4 for entering the cavity 906 via an insulated hole 9 which e.g. may comprise a dielectric. The resonator 41 is arranged within the cavity 906 and comprises a dielectric substrate 901 and two sides covered by thin superconducting films 902, 902' wherein the size or the area of the superconducting film 902' (and advantageously conducting plates) is smaller than that of the dielectric substrate 901 in order to provide dual mode operation of the resonator. Connectors 907, 908 are arranged for the input and output of microwave signals respectively and the connectors comprise pins 14 for capacitive coupling of the microwave signals in and out of the resonator.

Figs. 10a-10c illustrate embodiments 50A;50B;50C similar to that of Fig. 9 but wherein means are provided to enable fine tuning or calibration of the resonant frequency e.g. in order to compensate for the spread in material and the device parameters. The reference numerals correspond to the ones of Fig. 9. In the devices 50A, 50B of Figs. 10a and 10b respectively a dielectric or metal screw 12, 15 is arranged to provide the adjusting of the resonant frequency. In Fig. 10a the screw 12, which is moveable, is arranged at the top

of the cavity whereas in Fig. 10b the screw 15 is arranged at the bottom of the cavity. In Fig. 10c the resonant frequency is thermally adjustable via a thermal adjusting means. The thermal adjusting means here comprises an electrical heating spiral 13. Other appropriate heating means can of course be used and they can be arranged in a different manner etc., Fig. 10c merely being an example of how the thermal adjusting means 13 can be arranged. Of course also the screws of Figs. 10a and 10b can be arranged in other ways and it does not have to be screws but also other appropriate means can be used and they can be arranged in a number of different ways. In an alternate embodiment (not shown) one of the cavity walls or portion of a wall, or a separate wall, is movable to enable fine tuning or calibration.

However, via the screw 12 of Fig. 10a fine tuning of the resonant frequency is possible whereas via the screw 15 of Fig. 10b larger mechanical adjustments of the resonator cavity to achieve for example a change of its centre frequency, a channel reconfiguration etc. can be obtained.

Figures 11a, 11b and 12 illustrate embodiments with coupling between dual mode resonators forming small size tuneable low loss passband filters. Fig 11a shows a cross sectional side view of a four-pole electrically tuneable and adjustable filter 60, in a superconducting cavity housing forming a below cutoff frequency waveguide and Fig. 11b shows a top view of the four-pole filter 60 of Fig. 11a. Two dual mode resonators 111a, 111b are arranged in a superconducting cavity 111. The dual mode resonators may e.g. take the form of the resonators as illustrated in Figs. 7a, 7b. A DC bias voltage is supplied via the leads 4, as in the foregoing described embodiments via insulated holes 9 in the cavity. Connectors 117, 118 are provided for the input and output of microwave signals and the connectors are provided with pins 114 for capacitive coupling of the microwave signals. The two resonators 111a, 111b are coupled via a coupling pin 16 via an opening in an internal cavity wall.

Fig. 12 is a cross-sectional view of an electrically tuneable three-pole filter 70 with coupled circular parallel plate resonators. In this embodiment two loop couplers 127, 128 are illustrated for coupling microwave signals in and out of the resonators. Coupling between the three circular resonators 121a, 121b, 121c is provided via coupling slots 129.

Of course the principle of the invention can be applied to many other devices, merely a few having been shown for illustrative purposes. Moreover a number of different materials can be used and though for each embodiment merely one way of tuning has been explicitly shown, it is apparent that voltage tuning, or temperature tuning can be used in any embodiment. Also the shapes of the resonators or the superconducting films, as well as the non-superconducting films, and the dielectric can be arbitrarily chosen and moreover also multimode devices can be formed in any desired manner.

CLAIMS

1. Tunable microwave device (10A, 10B; 20A, 20B; 30A, 30B; 40; 50A, 50b, 50c; 60; 70) comprising a substrate (101; 701; 801; 901) of a dielectric material having a variable dielectric constant and at least one superconducting film (102; 702a, 702b; 802; 902, 902') arranged at least on parts of the dielectric substrate, wherein the dielectric substrate (101; 701; 801; 901) comprises a non-linear dielectric bulk material,
c h a r a c t e r i z e d   i n ,
that a conducting layer (103, 103) is arranged on each superconducting film on the side(s) thereof opposite to the dielectric substrate.

2. Device according to claim 1,
c h a r a c t e r i z e d   i n ,
that the dielectric substrate (101; 701; 801; 901) comprises a single crystal bulk material.

3. Device according to claim 1 or 2,
c h a r a c t e r i z e d   i n ,
that the superconducting film arrangement (102; 702a, 702b; 802; 902, 902') comprises a high temperature superconducting (HTS) material.

4. Device according to claim 3,
c h a r a c t e r i z e d   i n ,
that the dielectric material has low dielectric losses and high dielectric constants at cryogenic temperatures.

5. Device according to anyone of the preceding claims,
c h a r a c t e r i z e d   i n ,
that the superconducting film arrangement (102; 702a, 702b; 802;

902, 902') comprises films which are so arranged on the dielectric substrate (101; 701; 801; 901) that a resonator is formed.

6. Device according to claim 5,
characterized in,
that the superconducting films (102; 702a, 702b; 802; 902, 902') are arranged on at least two surfaces of the dielectric substrate (101; 701; 801; 901).

7. Device according to anyone of the preceding claims,
characterized in,
that the superconducting films are arranged directly on the dielectric substrate.

8. Device according to anyone of the preceding claims,
characterized in,
that a thin buffer layer is arranged between a superconducting film and the dielectric substrate.

9. Device according to anyone of the preceding claims,
characterized in,
that the non-superconducting layer(s) (103) comprise(s) normal conducting metal, e.g. Ag, Au.

10. Device according to anyone of the preceding claims,
characterized in,
that the thickness of the superconducting film exceeds the London penetration depth (λ_L).

11. Device according to anyone of the preceding claims,
characterized in,
that it is electrically tunable.

12. Device according to claim 11,
characterized in,
that the dielectric constant of the dielectric material is varied

by application of a voltage to the superconducting film(s).

13. Device according to anyone of claims 1-10, characterized in, that it is thermally tunable i.e. the dielectric constant is changed when the temperature is changed is temperature controlled.

14. Device according to anyone of claims 6-13, characterized in, that it forms a parallel plate resonator wherein the dielectric substrate comprises a resonant disk e.g. having a cylindrical rectangular or similar shape.

15. Device (20a, 20b; 40; 50a, 50b, 50c; 60) according to anyone of the preceding claims, characterized in, that at least one superconducting film (702a, 702b; 902') has an area at least slightly smaller than the corresponding area of the dielectric substrate (701a, 701b; 901) on which it is arranged to provide coupling between degenerate modes resulting in a dual mode operation resonator.

16. Device according to anyone of the preceding claims, characterized in, that at least two dielectric substrates are arranged on the outer opposite surfaces of which superconducting films are arranged and in that between each dielectric substrate a superconducting film is arranged in such a way that coupling is provided between the resonators comprising each a dielectric substrate providing a multimode resonator.

17. Device (20A, 20B; 60) according to claim 15 or 16, comprising means (705a, 705b) for controlling the coupling between at least two degenerate modes forming at least a two-pole tunable passband filter.

18. Device (30A, 30B; 40; 50A, 50B, 50C; 60; 70) according to anyone of the preceding claims,
c h a r a c t e r i z e d i n ,
that it is enclosed in a cavity (806a, 806b; 906, 906', 906"; 111; 112).

19. Device according to claim 18,
c h a r a c t e r i z e d i n ,
that it is a below cut-off frequency waveguide.

20. Device according to claim 18 or 19,
c h a r a c t e r i z e d i n ,
that the cavity is superconducting either comprising bulk superconducting material or normal material covered by a superconducting film, particularly a HTS material.

21. Device according to claim 20,
c h a r a c t e r i z e d i n ,
that coupling (10; 11; 14) means are provided for coupling in and/or out of micro-wave signals.

22. Device (10a, 10b, 10c) according to claim 20 or 21,
c h a r a c t e r i z e d i n ,
that second means (12; 15; 13) separate from the first tuning means are provided for fine-tuning or calibrating the resonant frequency of the resonator.

23. Device according to claim 22,
c h a r a c t e r i z e d i n ,
that said second means comprises a mechanically adjustable arrangement (12; 15) of, or within the cavity.

24. Device according to claim 22,
c h a r a c t e r i z e d i n ,
that said second means comprises mechanical (12; 15) and/or thermal adjusting means (13).

25. Device according to anyone of claims 18-24,
c h a r a c t e r i z e d in,
that the cavity comprises two sub-cavities either in the form of separate cavities or a divided cavity with each at least one resonator (111a, 111b) which resonators are connected to each other via interconnecting means (16) forming a multiple filter (60).

26. Device according to anyone of the preceding claims,
c h a r a c t e r i z e d in,
that the dielectric substrate e.g. comprises $SrTiO_3$ and in that the superconducting film(s) comprises YBCO.

27. Tunable microwave resonator comprising at least one dielectric substrate and superconducting films arranged on at least two sides of the substrate, first tuning means connecting (4) to at least one of the superconducting films, the dielectric substrate comprising a non-linear bulk material,
c h a r a c t e r i z e d in,
that on those sides of the superconducting films that are opposite to the substrate, normal conducting layers (103) are arranged, e.g. of Au or Ag.

28. Tunable microwave resonator (50A, 50B, 50C) according to claim 27,
c h a r a c t e r i z e d in,
that second tuning means (12; 13; 15) are provided for fine tuning or adjusting the resonant frequency of the resonator.

29. Tunable microwave resonator according to anyone of claims 27-28,
comprising at least two modes to form at least a dual mode resonator.

30. Tunable microwave filter (60; 70) comprising at least two resonators (111a, 111b; 121a 121b, 121c) arranged in a cavity arrangement (111; 112), each resonator comprising a dielectric

substrate on at least two surfaces of which a superconducting film arrangement is provided and first tuning means connecting to at least part of the superconducting arrangement for changing the dielectric constant (ϵ) of the dielectric substrate,

c h a r a c t e r i z e d i n ,

that the dielectric substrates are formed by a non-linear bulk material and in that coupling means (16; 129) are provided between at least two resonators (111a, 111b; 121a, 121b, 121c).

FIG. 1a

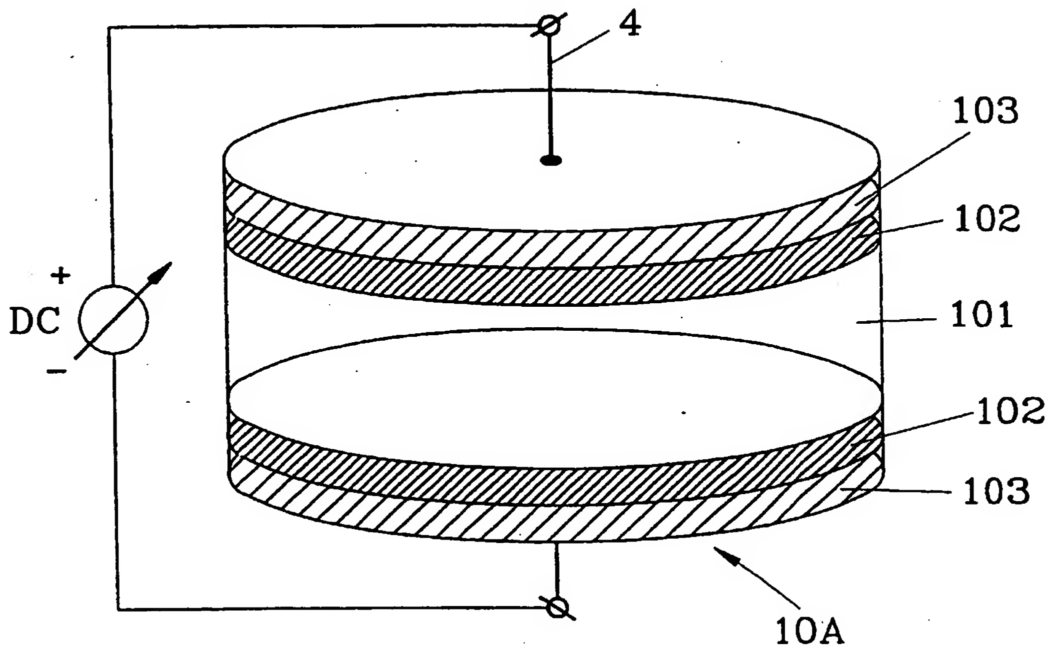


FIG. 1b

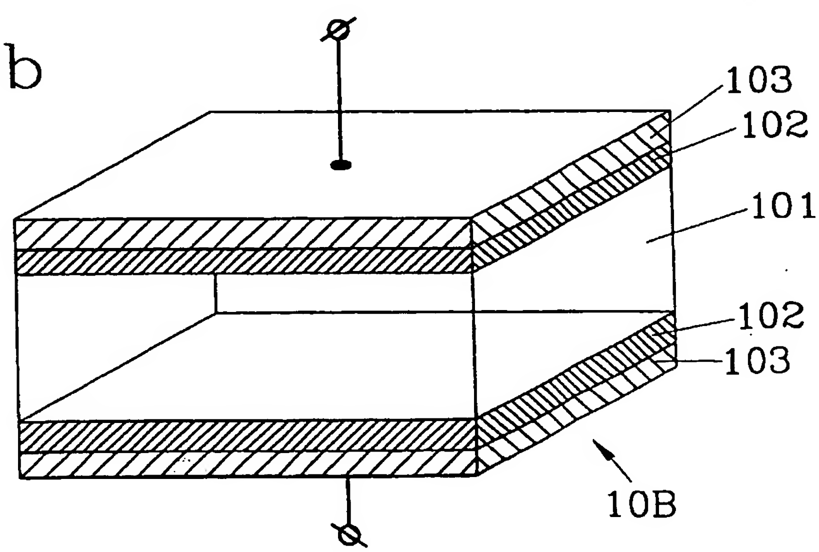


FIG.2

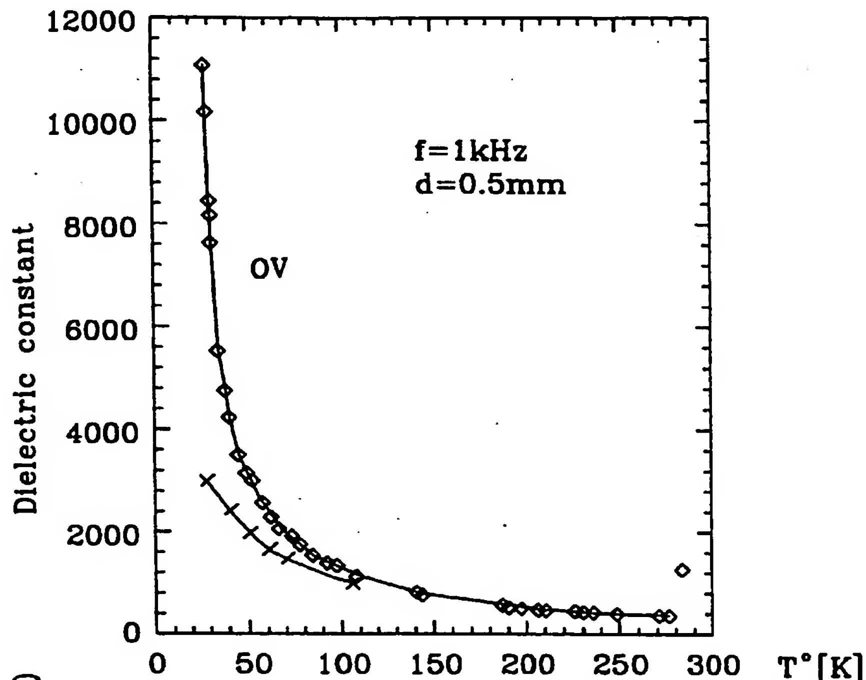

12000
10000
8000
6000
4000
2000
0
Dielectric constant
f=1kHz
d=0.5mm
OV
0 50 100 150 200 250 300
T°[K]

FIG.3

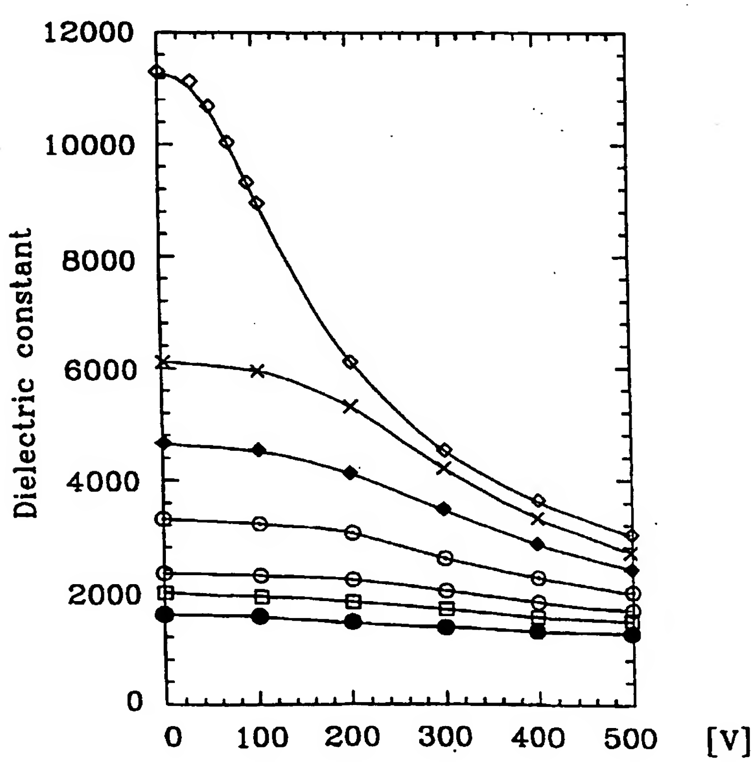

12000
10000
8000
6000
4000
2000
0
Dielectric constant
0 100 200 300 400 500
[V]

FIG.4

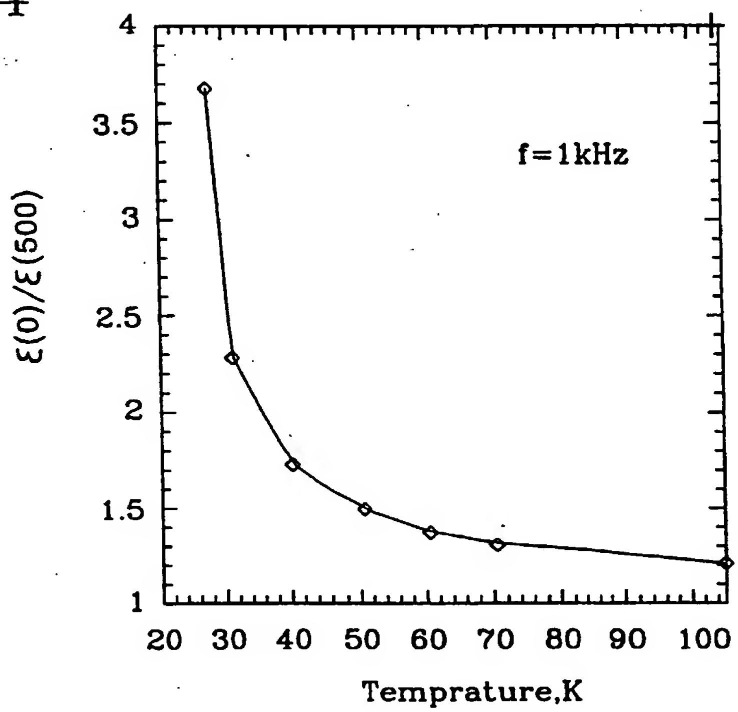

4
3.5
3
2.5
2
1.5
1
ε(0)/ε(500)
f=1kHz
20 30 40 50 60 70 80 90 100
Temprature,K

FIG.5

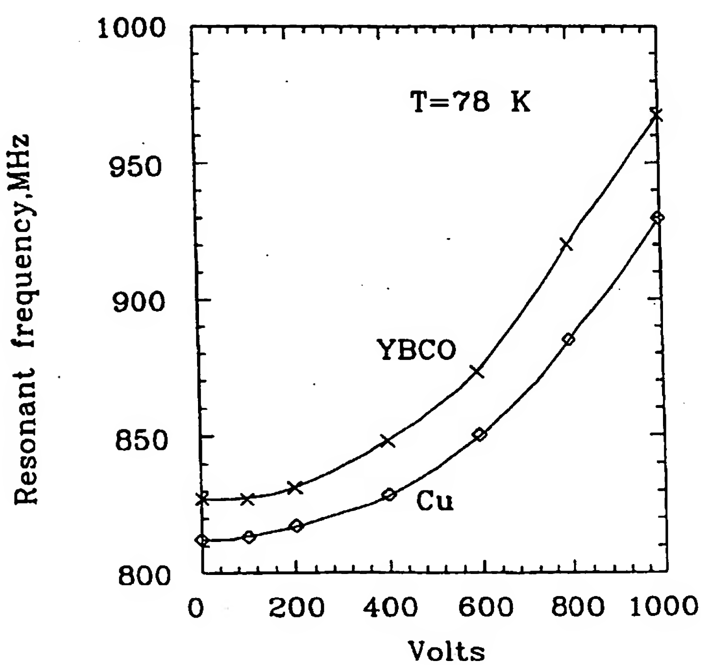

1000
950
900
850
800
Resonant frequency,MHz
T=78 K
YBCO
Cu
0 200 400 600 800 1000
Volts

FIG.6

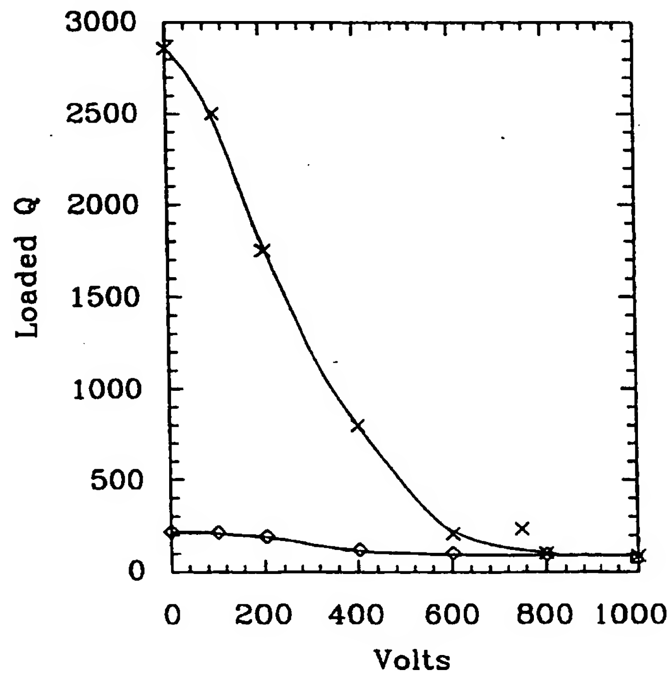

3000
2500
2000
1500
1000
500
0
Loaded Q
0
200
400
600
800
1000
Volts

FIG.7A

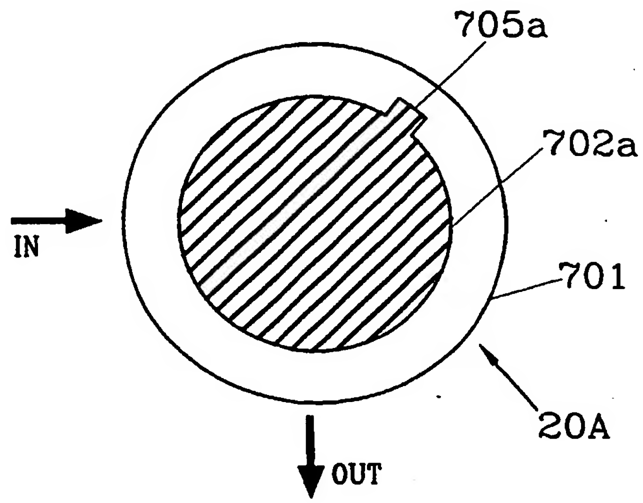


FIG.7b

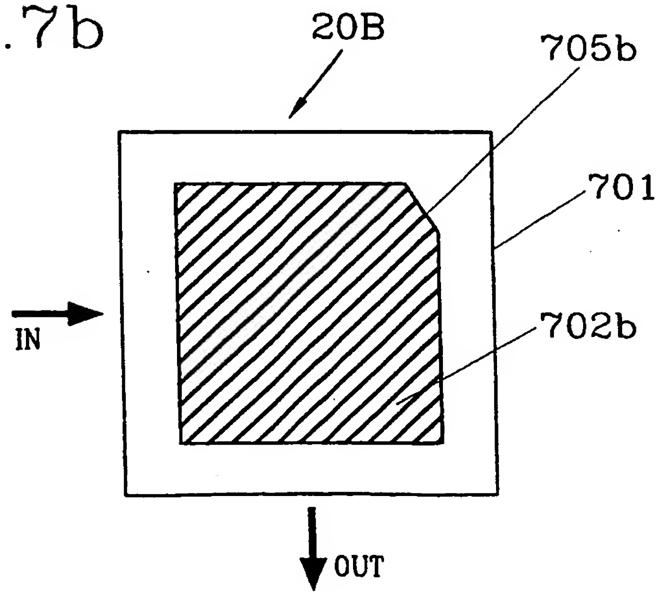


FIG.8a

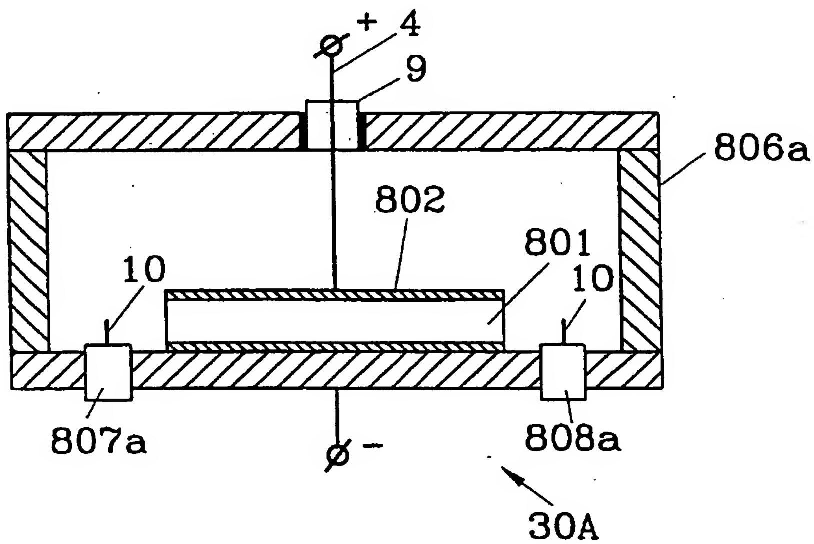

+ 4
9
806a
802
801
10
10
807a
808a
30A

FIG.8b

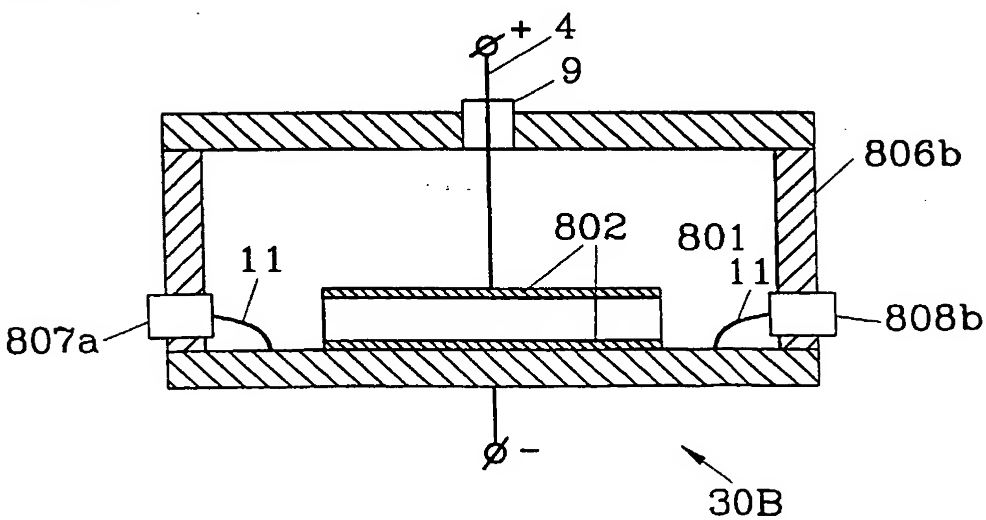

+ 4
9
806b
802
801
11
11
807a
808b
30B

FIG.9

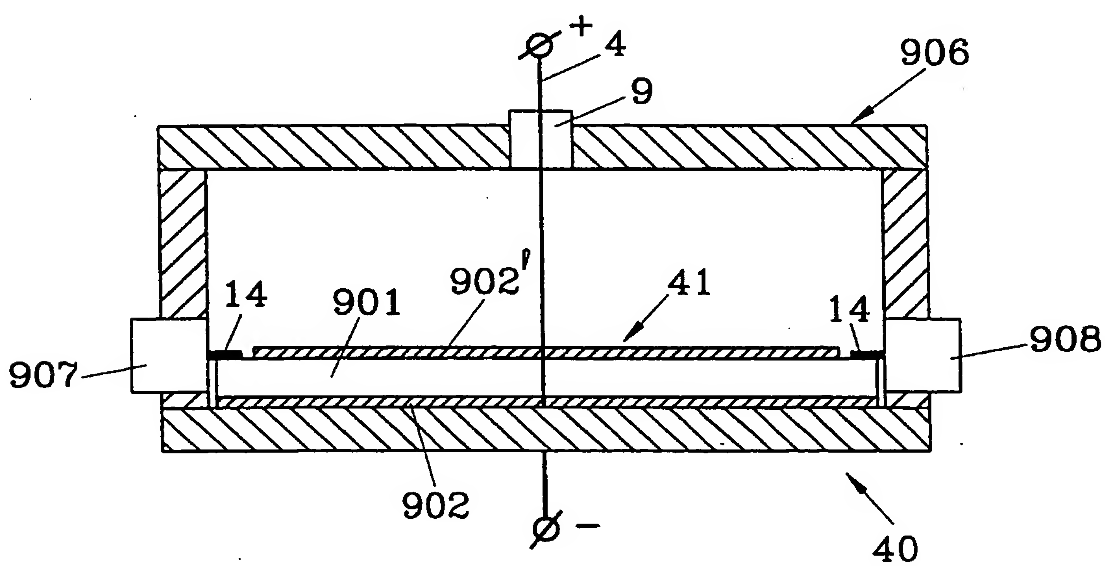

+ 4
9
906
902'
41
14
901
14
908
907
902
−
40

FIG.10a

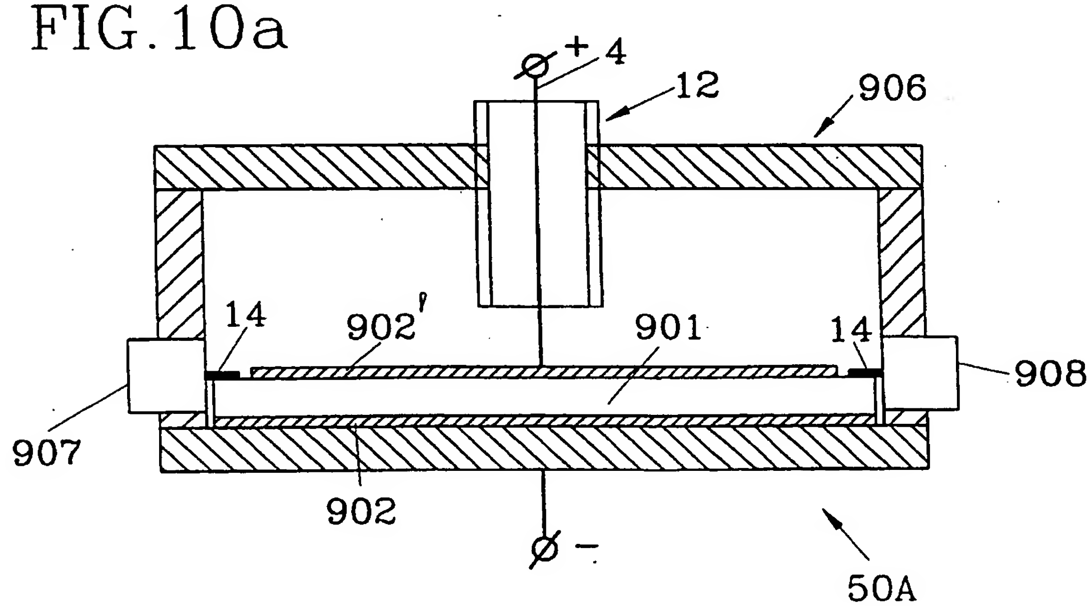

+ 4
12
906
14
902'
901
14
908
907
902
−
50A

FIG.10b

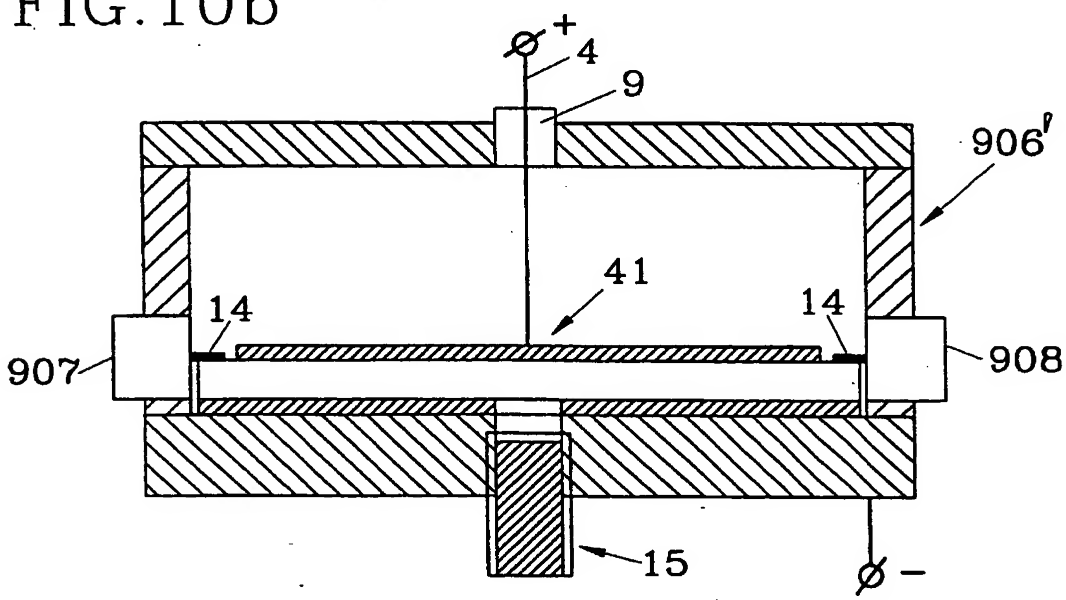


FIG.10c

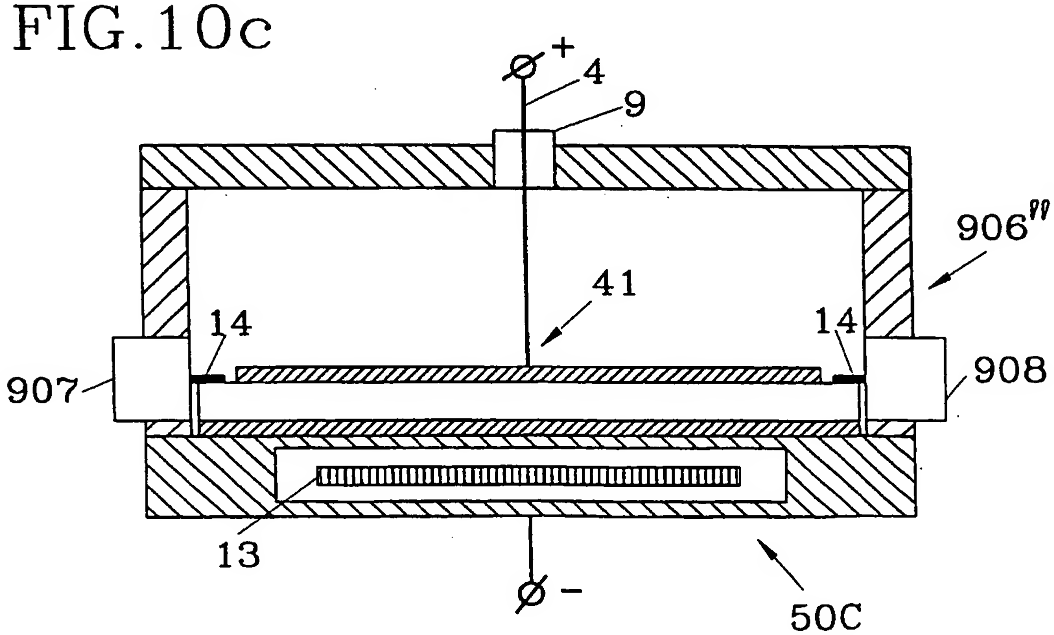


FIG. 11a

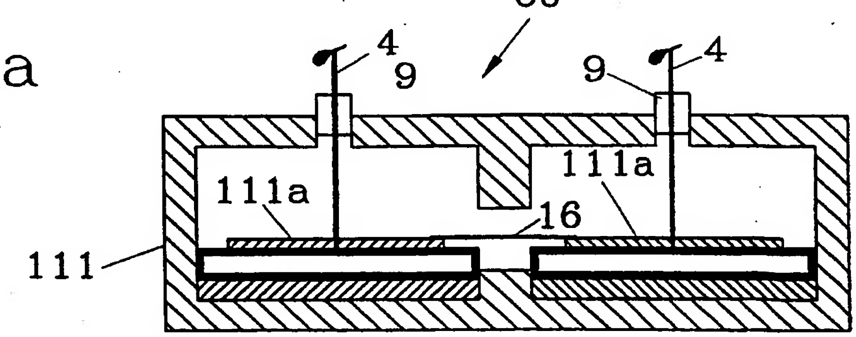


FIG. 11b

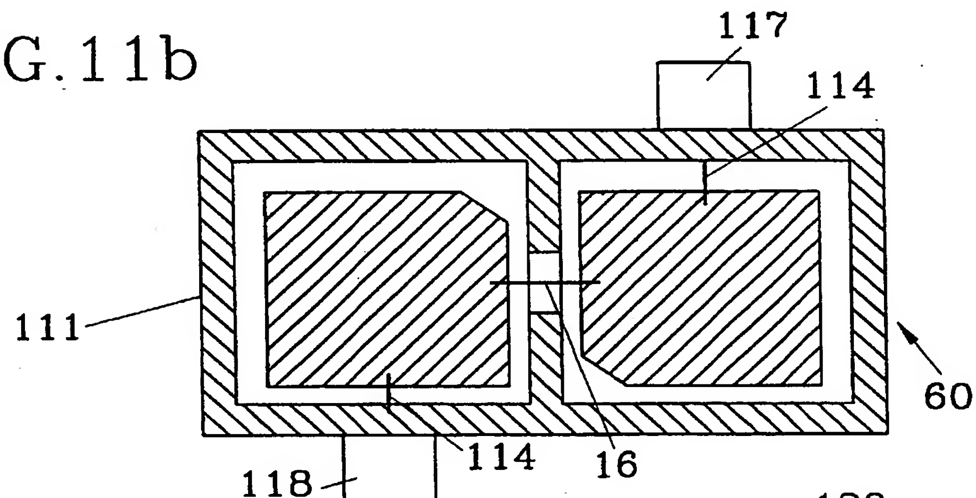


FIG. 12